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BNL C-AD
June 17, 2019

ON POLARIZATION PROFILE TOOLING FOR THE EIC

In the AGS

Y. Dutheil, PhD research - 2010-2014

The polarization is not defined by the projection of the spin vectors on the vertical axis but by the projection on the stable spin direction

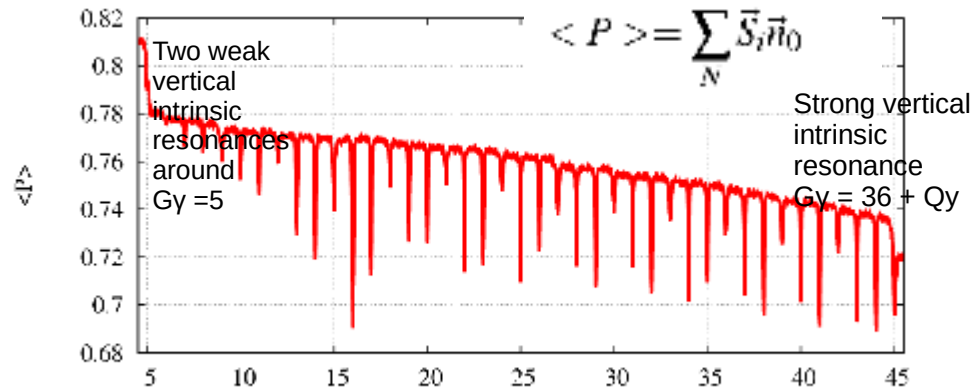


Figure 4.7 Average of the projected spin vector on the stable spin direction on the closed orbit during a typical multiturn tracking.

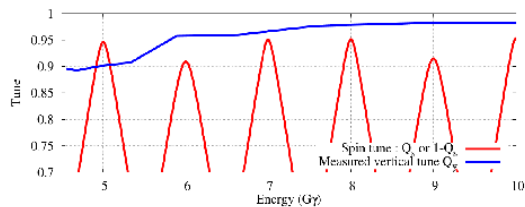


Figure 4.9 Fractional part of the vertical tune and spin tune at low energy as a function of the energy in the AGS.

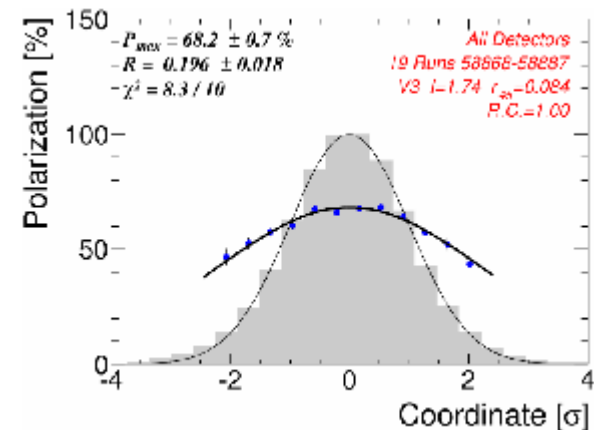
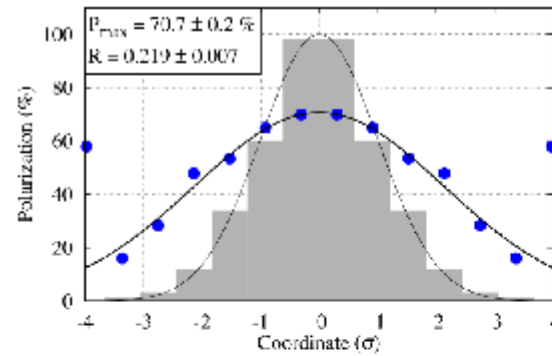
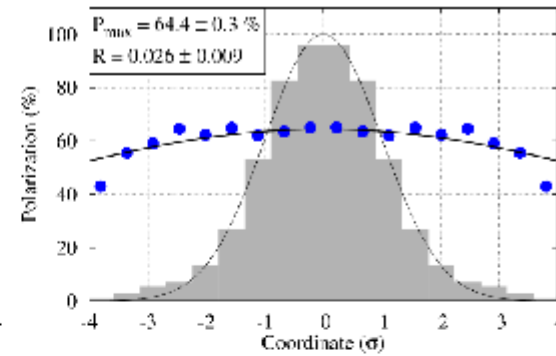


Figure 4.8 Measured horizontal polarization profile in the AGS at extraction energy. Grey: beam intensity profile; blue dots: polarization profile. This measurement took 5 hours.

- The profiles are expected to be symmetrical, so the binning is done symmetrically, effectively only filling half of the bins and symmetrizing afterwards. This allows mitigating the relatively small statistics.

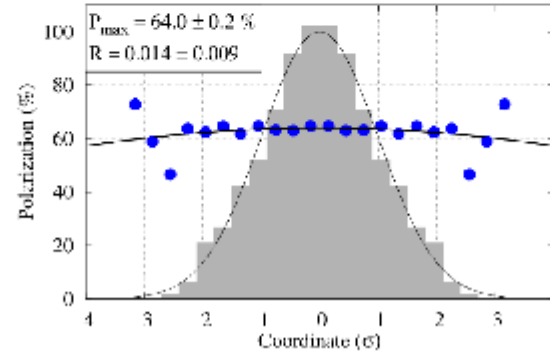


(a)



(b)

- This type of profile is usually obtained by tracking ~4-5000 particles. Accuracy on R not at its best.



Transverse emittances:

$$\epsilon_z^{N,95\%} = \beta\gamma 6\pi \sqrt{\langle z^2 \rangle \langle z'^2 \rangle - \langle zz' \rangle^2}$$

Longitudinal emittance:

$$\epsilon_l^{N,95\%} = 6\pi \frac{C}{h2\pi\beta_c} \sigma(\phi) M_0 \gamma \beta^2 \sigma(dp/p)$$

Polarization profiles in a bunch at $\sqrt{s} = 45.5$ in the AGS, from multiturn tracking. *Horizontal (a), vertical (b) and longitudinal (c) planes.*

- Simulated polarization profiles do not depend on the location around the AGS as the effect of the dispersion is removed.
- Tracking 4~5000 particles over 130,000 turns (the AGS cycle) requires 2+ CPU hours per particle. Which also means 2hrs overall on a computer farm – NERSC.

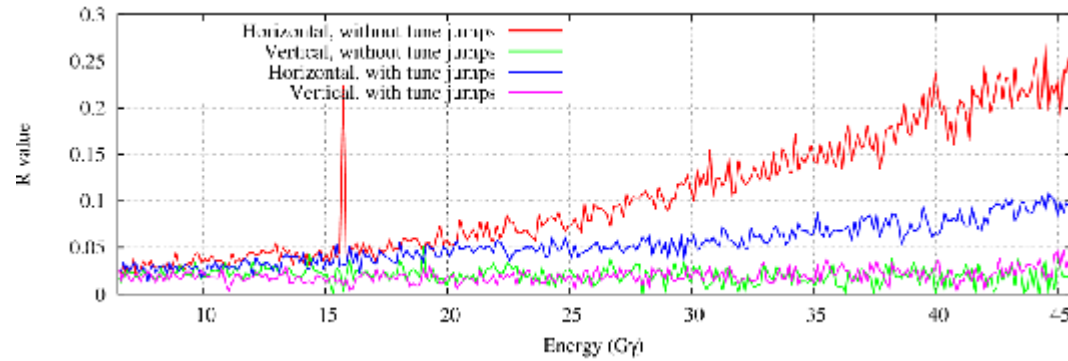
Effect of the sample size on the mean polarization and horizontal R-value.

Number of particles	1000	2000	4416	17664
Mean Polarization(%)	84.16	81.65	81.31	81.31
Standard deviation	5.2	0.5	0.15	-
Mean horizontal <i>R</i> value	0.189	0.192	0.194	-
Standard deviation	0.012	0.014	0.007	-

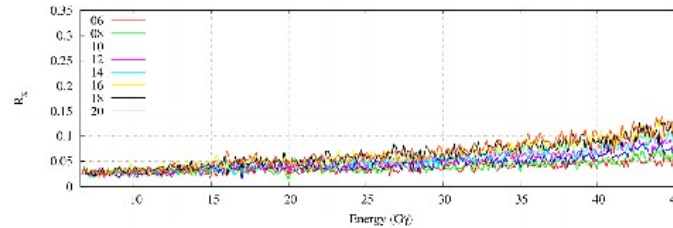
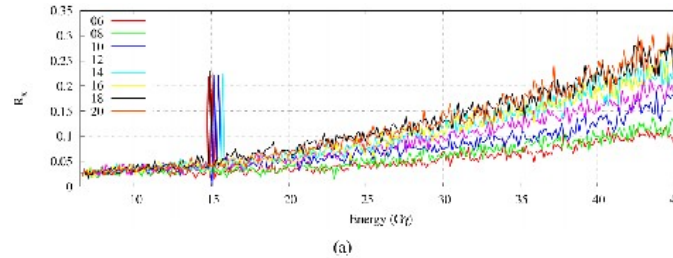
Comparison of simulated polarization profiles with measurements (AGS ppRun 14). Measurements show unexpectedly strong V profiles.

Measured [5]		Simulated		Machine conditions
R_x	R_y	R_x	R_y	
0.206 ± 0.020	0.181 ± 0.033	0.250 ± 0.007	0.021 ± 0.007	Without tune jumps
0.127 ± 0.019	0.124 ± 0.026	0.100 ± 0.007	0.035 ± 0.007	With tune jumps

Simulated polarization is qualitatively conform to expectations. Measured values of horizontal polarization profiles are successfully predicted by tracking.

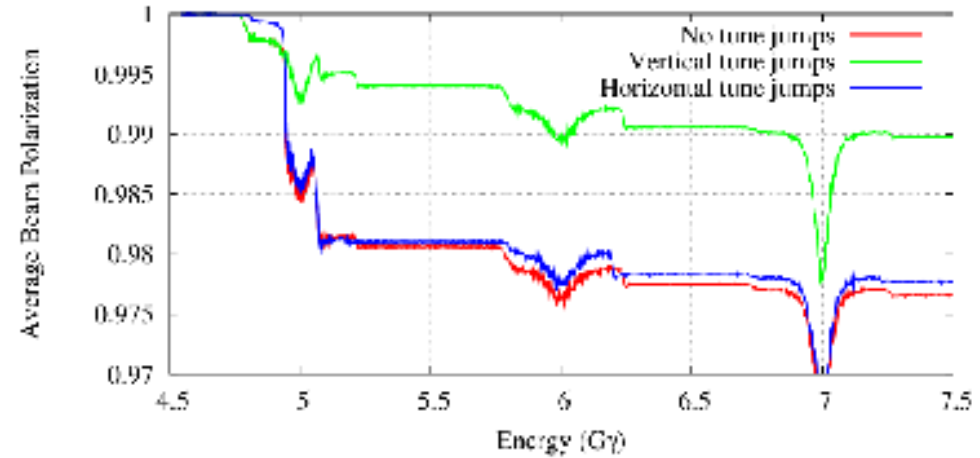
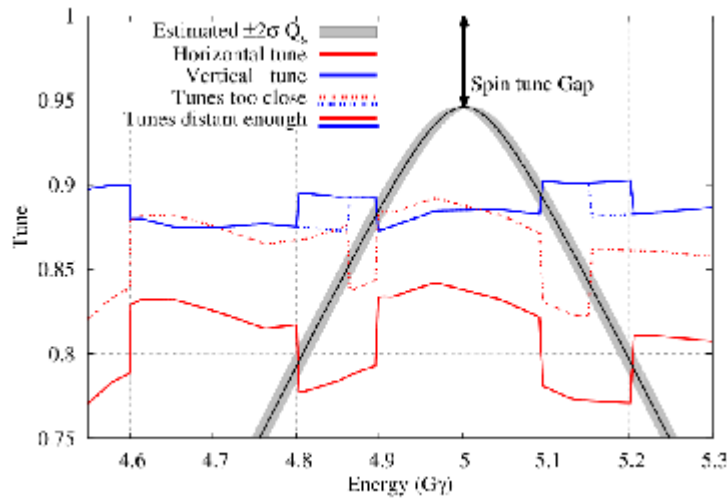


Polarization profiles from bunch tracking, from Gy = 6.5 to 45.5, accounting for typical beam and machine conditions.



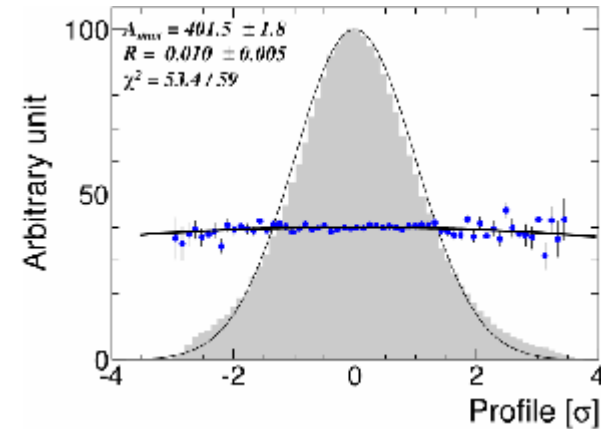
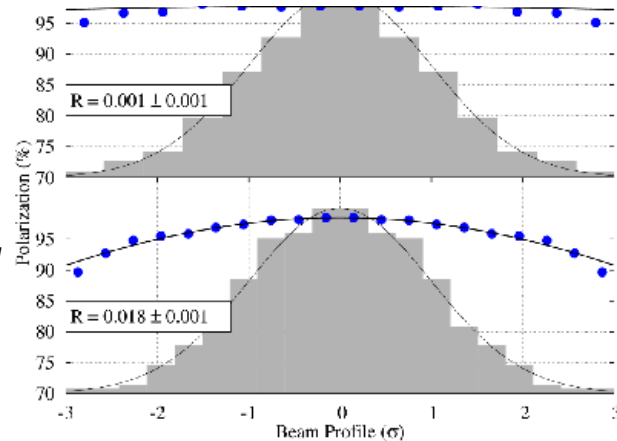
Simulated horizontal polarization profile as a function of energy for different initial beam horizontal emittances (in 95% π mm.mrad normalized and at Gy = 6.5) without (a) and with tune jumps (b).

Vertical tune jumps at $G\gamma=5$



Average bunch polarization over $G\gamma = 4.5 \rightarrow 7.5$

At $G\gamma = 7.5$: H and V polarization profiles obtained from tracking over $G\gamma = 4.5 \rightarrow 7.5$.

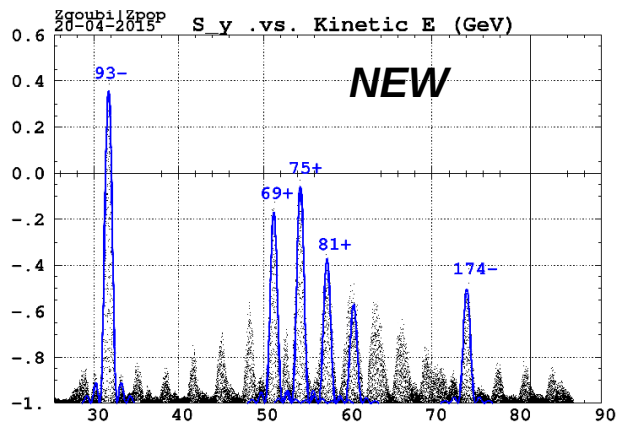
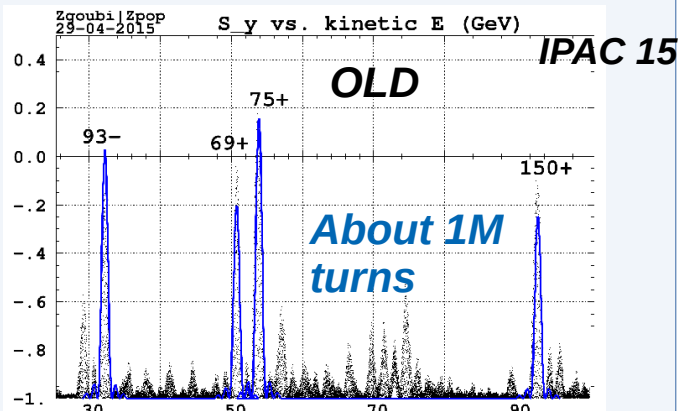


Vertical polarization profile, measured

In RHIC

A lot has been done over the years, typically amenable to polarization profile computation

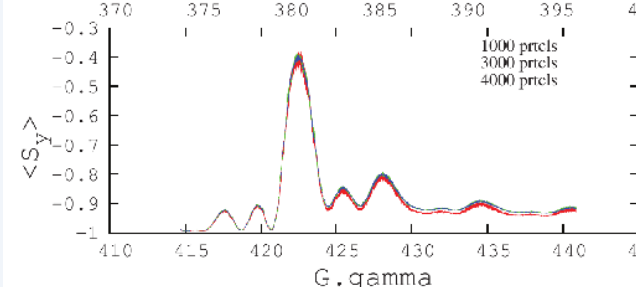
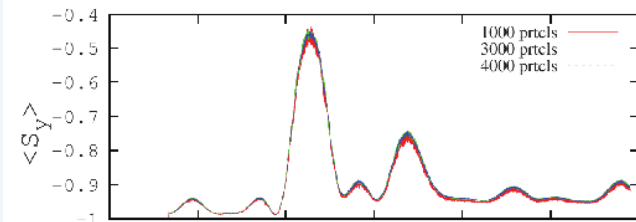
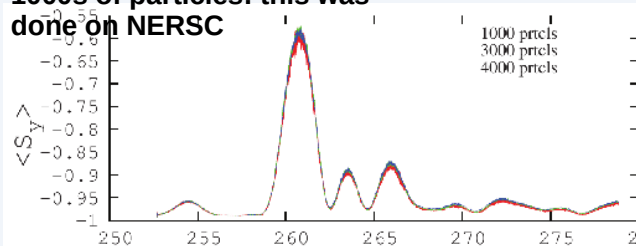
6D+spin. Comparing RHIC optics, preparation Run 15.
Blue envelop is theory [SYL]!



Code benchmarking,

6D+spin, tracking 1000s-particle bunches

1000s of particles: this was done on NERSC



Average of the projection of spins on the vertical, turn by turn, at $G_y = 231+Q_y, 411-Q_y, 393+Q_y$.

IPAC 12

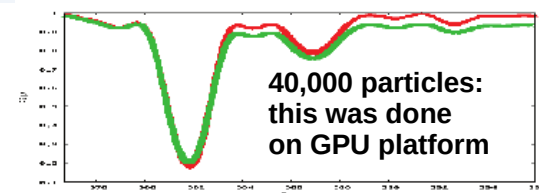


Figure 8: Crossing of 411 Q_y , 4-D tracking (red curve) and 6-D tracking (green curve).

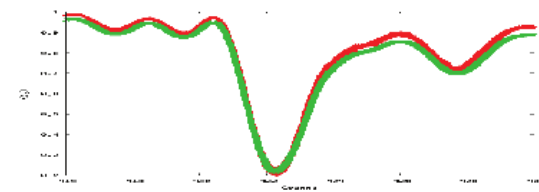


Figure 9: Crossing of 393 $-Q_y$, 4-D tracking (red curve) and 6-D tracking (green curve).

Table 1: Polarization Transmission

	Orbits set		No orbit	
	At start	At end	At start	At end
(1) 231+ Q_y :				
$\langle S_y \rangle$	-0.9889	-0.9834	-0.9891	-0.9889
Polar. ratio	1	0.99444	1	0.99987
(2) 411- Q_y :				
$\langle S_y \rangle$	-0.9864	-0.9498	-0.9871	-0.9777
Polar. ratio	1	0.96284	1	0.99052
(3) 393- Q_y :				
$\langle S_y \rangle$	-0.9939	-0.9324	-0.9943	-0.9624
Polar. ratio	1	0.9382	1	0.9679

These past months: simulation of RHIC spin-flipper, 6D+spin

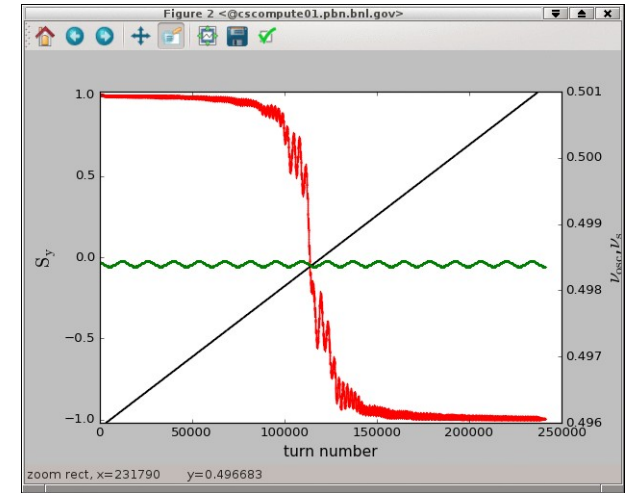
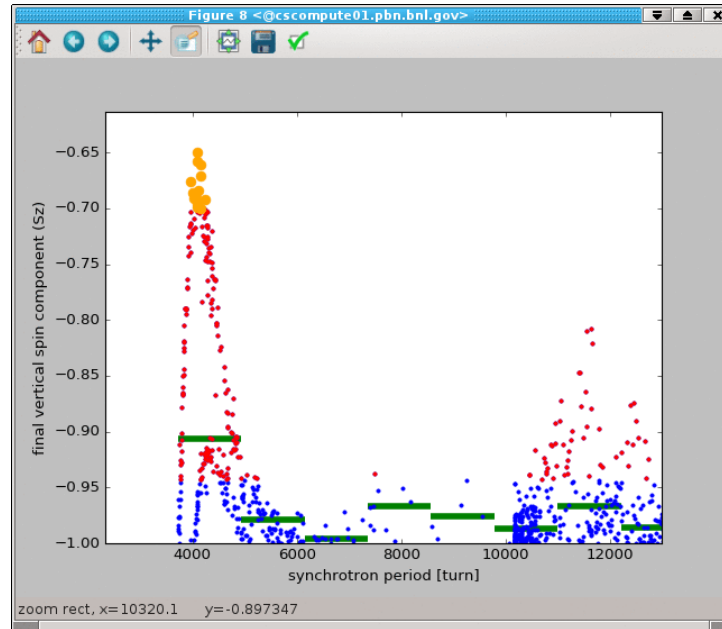
Petra Adams
C-AD OP

- A sweep at 24GeV requires up to 250,000 turns (3 sec.)
- Shorter at 255 GeV, < 1 sec., 70,000 turns

Last night:

a correlation between
synchrotron frequency
and final polarization

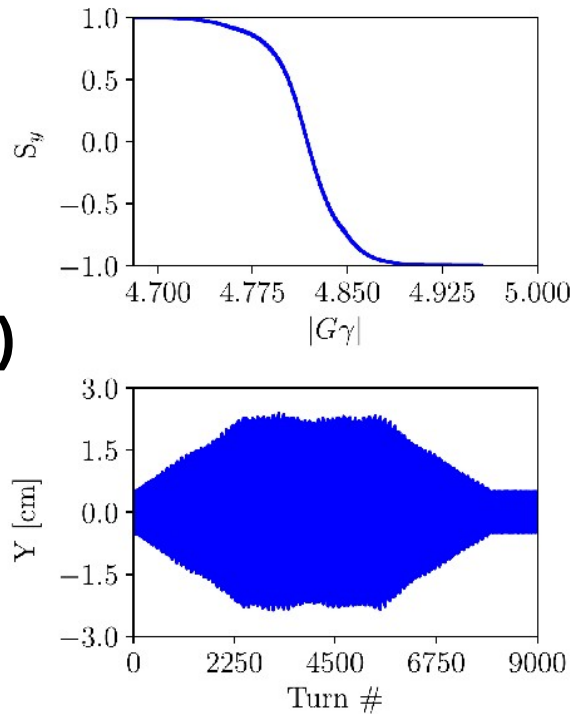
Average of the vertical
spin component in
bins



/home/cfsd/padams/
spin_flipper/blue_injection/
noIPBumps/Nersc/
Dp3.45mrad/
9MHz197MHz/
inj_Dp3.45mrad_sweep234
000_edisoned/Run1

At RHIC - There is more 6-D spin tracking, amenable to polarization profile studies:

- ^3He in Booster, high-rigidity injection in AGS (Kiel Hock, C-AD OP, PhD research, 2015 - on)
- D is in the plans



The mechanical design is shown in Fig. 2, and shows no programmatic drawbacks.

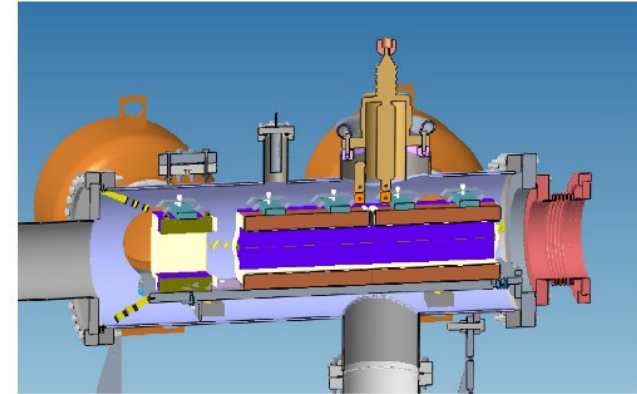
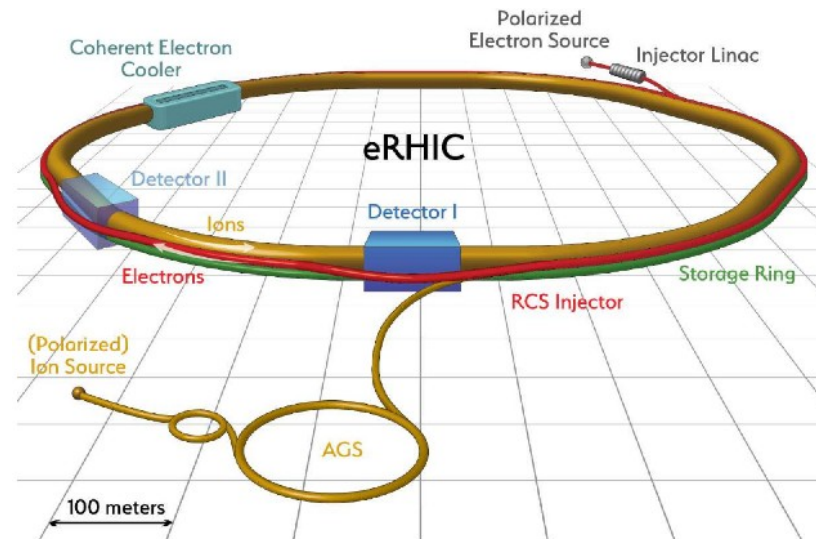
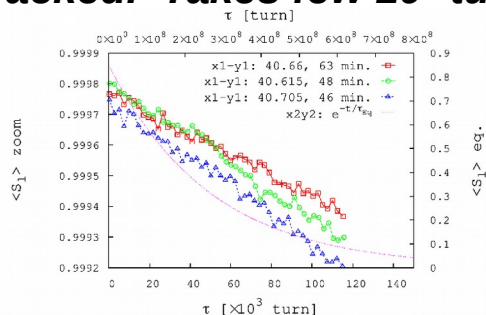


Figure 2: Cross section of the new assembly for the E3 section of the Booster. Inside the transparent vacuum chamber is the new AC-dipole, and a new tune kicker, can be seen. On the exterior of the vacuum chamber are the feed-throughs for the two magnets.

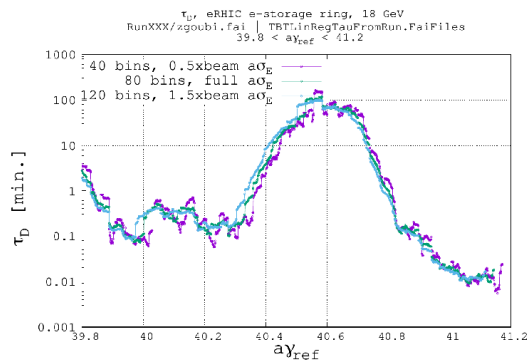
Some extra ads: electrons.

In eRHIC e-storage ring

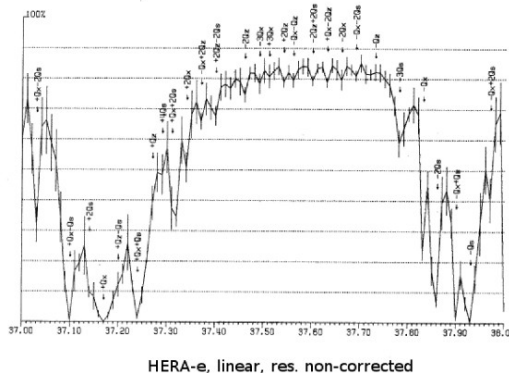
Steve's Tepikian lattice, time dependence of 6-D polarization is tracked. Takes few 10^4 turns.



Resulting polarization vs. ring rigidity - awaiting polarization profile criteria...

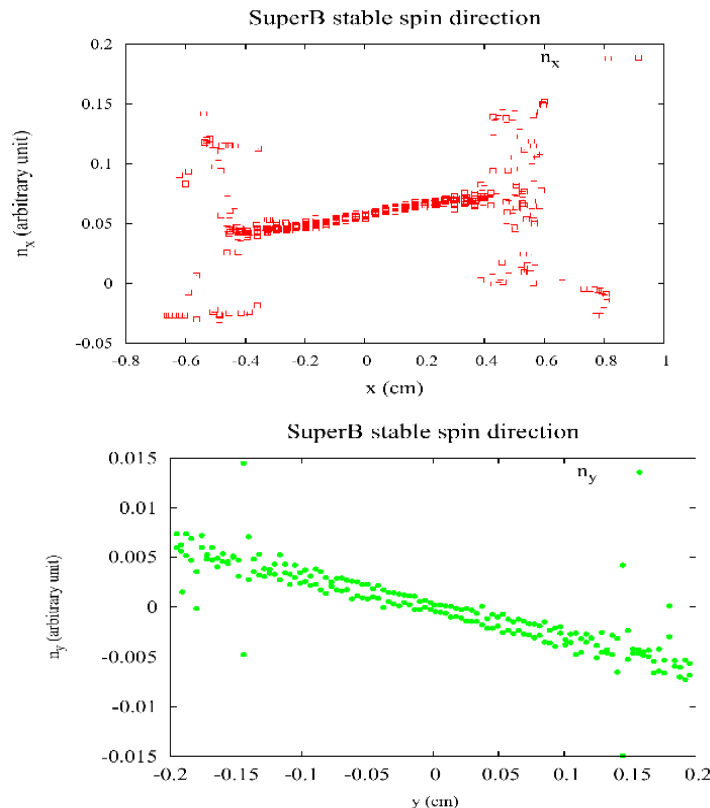


@ HERA for comparison



ISF is a sub-product of ray-tracing capabilities. e.g., @ Super-B:

- *Spin dynamics tool developments for **ISF computation** at super-B,*
N. Monseu (PhD research) – cf. IPAC 11
- Time-wise this is fine – there is clever, rapid algorithms,
and see next slide



**Finally, to be brief: there is more
6-D+spin hadron (and electron) tracking
amenable to beam polarization profile,
@ JLab EIC**

- See Morozov et als.,
IPAC and other joint BNL-JLab EIC meetings

CPU-wise

- Polarization profiles may require several 1000s of particles, to be tracked up to several 100,000s turns

We don't want tracking trials to take too long...

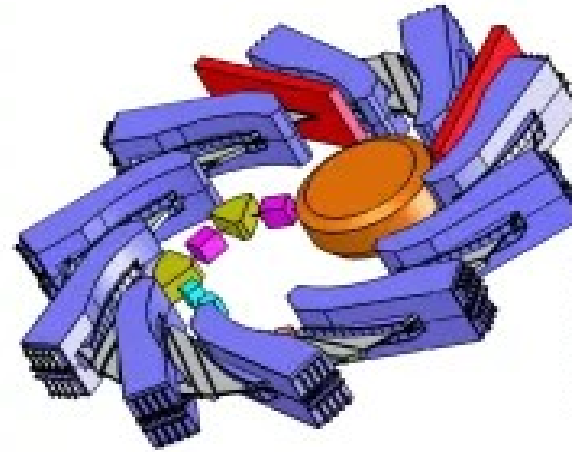
We work on NERSC → duration of tracking does not depend on # of particles

Doable, essentially: at most a matter of overnight computation

- Basic data:
 - RHIC: 1000turns/CPU-minute. On a recent CPU, crossing a resonance takes $\sim 10^5$ turns, [~1 hr](#)
 - RHIC spin flipper: A sweep at 24GeV requires up to 250,000 turns (3 sec flight time) → [~2 hrs](#)
 - eRHIC e-storage ring: computing polarisation survival requires a few 1000 turns, 10 x less than RHIC → [0.2 hrs](#)

Send us your student

We will teach her/him how to compute polarization profiles in the EIC and A rings



Accelerator Concepts Covered:

- Electron Ion Colliders
- Fixed-Field Accelerators
- Energy Recovering Linacs
- Medical Synchrotrons
- More

WORKSHOP INFO

TARGETS

Days begin with presentations on current applications of Zgoubi by industry and academic researchers.

TUTORING

Afternoons offer hands-on tutorials using Zgoubi code based on the existing data.

DATES

August 26-28, 2019

LOCATION

Bozeman
770 10th St.
Bozeman, ID 83609

ZGOUBI FOR THE NEW CENTURY

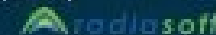
The goal of the Zgoubi Workshop is to provide the exchange of knowledge about the Zgoubi code. Presentations, an important scientific applications will motivate the associated particle. Bringing together both developers and scientific users allows for coordinated development, leveraging expertise from both groups and resulting in new tools and interfaces having consistent approaches.

The particle tracking code Zgoubi evolved from a tool for modeling spectrometers in 1992 to what it is today, one of the most complete single-particle dynamics codes. Used by labs worldwide for a wide range of particle accelerator modeling tasks, Zgoubi is especially valued for studies of polarization in electron-ion colliders, as well as for studies of the complex dynamics in fixed-field accelerators (FFAs) and medical synchrotrons.

Organizing Committee

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| • Dan Ales (Chair) | • Fenglin Lin |
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